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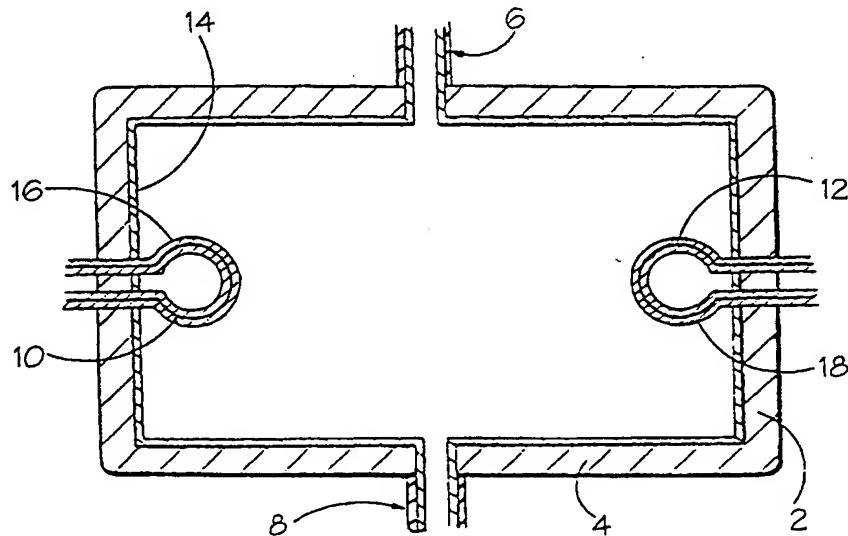
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(54) Title: APPARATUS AND METHOD FOR DETERMINING DIELECTRIC PROPERTIES OF AN ELECTRICALLY CONDUCTIVE FLUID



(57) Abstract

An apparatus is disclosed for determining dielectric properties of an electrically conductive fluid. The apparatus comprises an electromagnetically resonant cavity (2, 4, 6, 8) which may form part of a pipeline. An insulating layer (14) isolates the cavity's conductive wall from fluid within the cavity. An emitter antenna (10) and associated drive electronics are provided for emitting electromagnetic radiation into the cavity and the antenna is electrically isolated from fluid in the cavity. Means (12) are also provided for detecting resultant electromagnetic radiation in the cavity. The apparatus may be used in multi-phase metering.

DESCRIPTION

APPARATUS AND METHOD FOR DETERMINING DIELECTRIC PROPERTIES OF AN ELECTRICALLY CONDUCTIVE FLUID.

The present invention is concerned, in its broadest aspect, with an apparatus for and method of determining dielectric properties of an electrically conductive fluid. The invention is applicable in particular to the monitoring of multi-phase flows such as are found in oil pipelines.

The flow of material from an oil well typically contains not only crude oil but also other constituents, gas and water generally being the most significant of these. Other constituents such as sediment and algae are typically present in relatively small quantities. It is often necessary to monitor the relative proportions of the major constituents of the flow. One reason for this is to judge when a given well is becoming exhausted, signalled by a decline in the proportion of oil.

The traditional technique for this monitoring has involved separation of a sample of the material into its constituents, allowing straightforward single phase monitoring techniques to be used. While effective, processing systems based on this technique are somewhat inflexible in terms of their capability to handle fluctuating flow rates, varying water content and changes in the physical properties of the constituent fluids.

The technique also involves an undesirable time lag between extraction of the material at the well head and assessment of its constituents, not least because the assessment has to be made after separation of the materials on the rig itself -

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It is considered that in order to improve the accuracy of MPM devices it is important to monitor a third bulk property of the flow (aside from density and gamma ray attenuation) and that as yet no appropriate technique has been proposed for accurately monitoring an appropriate property.

The reason for the need for a third property measurement may be simply stated. It is necessary in a three phase flow to establish three unknown quantities - the proportions of the three constituents (eg. oil, gas and water). To this end, three simultaneous equations, one contributed by each monitored property, are required.

There has been at least one project which attempted to monitor, as the necessary third property, the effect of the flow on the propagation of electromagnetic radiation through it. This project faced an important problem. Flows emerging from an oil well head are electrically conductive due, among other factors, to their inclusion of salt water. Conventional technical teaching, based on the application of Maxwell's equations, is that electromagnetic radiation of wavelengths cannot be efficiently propagated through a conductive medium.

The solution adopted by the previous project was to use high power electromagnetic radiation. To provide this power it was necessary to use a magnetron, which operated at a power of the order of 1 Kilowatt. and at a frequency of 2.46 GHz. Due to the use of a magnetron to supply this radiation, its frequency was non-adjustable. The radiation was input to a resonant cavity, through which the flow was passed. The cavity walls were conductive and were exposed to the flow itself. Due to the resonance requirement, the dimensions of

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comprising an electromagnetically resonant cavity defined by an electrically conductive boundary; an inlet through which the fluid can be introduced into the cavity; an insulating layer whereby the cavity boundary is electrically isolated from fluid material within the cavity; an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and means for detecting resultant electromagnetic radiation within the cavity.

Experiments carried out by the inventors have confirmed that using such an arrangement measurements of dielectric properties can be made without the need for the high power provided by a magnetron. The arrangement can serve as a dielectric permittivity sensor. Dielectric properties at a radio and microwave frequencies can be measured. In prototype arrangements, a simple loop aerial driven by an electronic oscillator has proved adequate by virtue of the efficient propagation of radiation through the fluid material made possible by the arrangement. As compared with the previous magnetron apparatus, this makes possible great simplification and cost saving, as well as other benefits which will become clear below.

The fluid in question may contain some solids, as typically does a flow of material in an oil extraction pipeline.

With regard to the frequency of radiation emitted into the cavity, it is considered that the present invention is particularly applicable to radio and microwave frequencies. The frequency range used is in part determined by the

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wall whose inner surface is covered by an internal insulating layer by which the wall is electrically isolated from the fluid material within the cavity. The insulating layer may be a low loss dielectric. Ceramic can be used.

It is particularly preferred that the resonant cavity has an inlet and an outlet such that the fluid material can flow through the cavity. This makes it possible to monitor, continuously if required, the properties of a fluid flow.

In a currently preferred embodiment of the present invention, the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

Alternatively or additionally, the means for detecting electromagnetic radiation within the cavity may comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio. The effect is to provide an indication of the reflected power at the emitter antenna.

In accordance with a second aspect of the present invention, there is provided a device for monitoring the constituents of a fluid flow, the device comprising an apparatus according to the first embodiment of the present invention. Of particular importance is the case where the device is adapted for monitoring the constituents of a flow of material in an oil pipeline. Multi-phase metering can be carried out by such a device.

In such an embodiment, the resonant cavity may be formed by a portion of the pipeline. Preferably, the electrically conductive boundary defining the resonant

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In a preferred embodiment, the calculating means operates by calculating for a set of possible permutations of flow constituents the expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

The calculating means may comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents. The quantities in question may be the frequencies of a selected resonant mode of the cavity.

In accordance with a third aspect of the present invention, there is a method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an electromagnetically resonant cavity defined by an electrically conductive boundary which is electrically isolated from the fluid by an insulating layer, emitting electromagnetic radiation into the resonant cavity by means of an antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

Preferably, the method comprises varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity. The frequency variation may be continuous. The results are preferably analysed to determine the position of at least one resonance peak within the cavity.

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is filled with gas;

Figure 3 corresponds to Figure 2 but represents the case where the cavity is filled with oil;

Figure 4 corresponds to Figure 2 but represents the case where the cavity is filled with water;

Figure 5 is a graph having the same axes as Figure 2 (albeit with different ranges) on which signal amplitudes corresponding to cavities filled with gas, oil and water are juxtaposed;

Figure 6 is a table of observed fundamental resonance frequencies of the cavity corresponding to a range of cavity contents;

Figure 7 is a graph of the results for oil/gas mixtures tabulated in Figure 6 showing resonant frequency in MHz on the vertical axis against, on the horizontal axis, the percentage of oil (the upper row of figures along this axis) and the percentage of gas (the lower row of figures on this axis);

Figure 8 corresponds to Figure 7 except that the results shown are for water/gas mixtures, the percentage of water being indicated by the upper row of figures on the horizontal axis and the percentage of gas being indicated by the lower row of figures;

Figure 9 corresponds to Figure 7 except that the results shown are for water/oil mixtures, the percentage of water being indicated by the upper row of figures along the horizontal axis and the percentage of oil being indicated by the lower row of figures;

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by a solid triangle, values for water being indicated by a solid square and values for gas being indicated by a phantom triangle; and

Figure 18 is a graph of frequency (in Mhz on the horizontal axis) against phase shift (in degrees on the vertical axis).

The prototype apparatus illustrated in Fig. 1 has been used for proving the feasibility of the present invention. The apparatus comprises a cylindrical microwave cavity defined by copper side and end walls, 2, 4 and having an axial inlet 6 and outlet 8 by means of which flow material can be passed through the cavity. The cavity had, in this prototype device, a length of 158mm and a diameter of 189mm. There is however scope for variation of the shape and dimensions of the cavity. In the experimental arrangement illustrated, a pump (not seen) is used to circulate the test medium and so provide a flow.

Within the cavity is a first loop aerial 10 serving as a microwave transmitter and a second loop aerial 12 serving as a microwave receiver.

An important feature of the apparatus is an electrical insulation layer 14 provided on the interior of the cavity walls to electrically isolate the cavity walls from the cavity's interior. Further insulation layers 16, 18 are provided on the transmitter aerial 10 and the receiver aerial 12, which are thereby also electrically isolated from the interior of the cavity.

Experiments carried out using the prototype apparatus have confirmed that by virtue of the electrical isolation of the cavity and aerials from the cavity contents, it becomes possible to efficiently couple electromagnetic radiation into

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is present. This is due to the higher dielectric constant of oil (2.2) compared with gas (1.0).

When the cavity is filled with water, an extreme shift of resonant frequencies occurs due to the high dielectric constant of water (approximately 80).

The effect of the cavity contents on the positions of the resonance peaks is illustrated most clearly in Fig. 5, on which the three curves are superimposed, the left-most curve corresponding to a water filled cavity, the centre curve corresponding to an oil filled cavity and the right-most curve corresponding to a gas filled cavity. On each curve, the label R denotes the cavity's fundamental resonant mode. Its frequency shift is clearly apparent.

Figs. 2 to 5 concern the simple cases in which only one material is present within the cavity. The inventors have however studied the more complicated case of a mixed flow, and in particular measured the effect of a range of mixed flows on the frequency of the fundamental (lowest frequency) resonant mode within the cavity.

In Fig. 6, the experimentally observed frequency of the fundamental mode is tabulated against a range of proportions of gas, water and oil. The trends are more easily appreciated with reference to Figs. 7 to 10, which show:

Fig. 7: the variation of the frequency of the fundamental mode for an oil/gas combination;

Fig. 8: the variation of the frequency of the fundamental mode for a water/gas combination;

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prototype apparatus, including the base of zero flow - ie. a static mixture. Even when the flow is stopped, so that the gas forms a single body above the liquid, it is found that the spectrum is largely unchanged.

To assess the possible effect of further constituents in the flow (in addition to oil, gas and water) experiments have been carried out in which a proportion of sand is added. The results are graphed in Fig 12, where curve A was obtained when the cavity contained only water while curve B was obtained using 95% water with 5% sand. The dielectric constant of sand is approximately 4.5, and the sand therefore caused a detectable shift in the first resonance peak.

Temperature dependence of the resonance peaks has been studied using a cavity filled with water and pumped at a constant speed. As the temperature is increased it is found that the frequency of the first peak increases. The effect is caused by a decrease in the value of the dielectric constant ϵ with increasing temperature. The velocity of microwaves in water depends on the square root of the relative permittivity as follows.

$$v = \frac{C}{\sqrt{\epsilon}}$$

The frequency within the cavity is proportional to the velocity of the microwave so that if the cavity resonates at 150MHz at 30°C, the same cavity will resonate at 161MHz at 60°C.

As an aid to the automation of the sensor system the phase relationship between the input and output signals for the cavity has been investigated. The

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proportions of the flow constituents. In the system described herein, this is achieved by means of a Neural Network.

The Neural Network of the existing system has been implemented using the C++ language. The currently preferred one hidden layer Network is illustrated in Fig. 13 and is specified in terms of input, number of modes in the hidden layers and outputs. The weighting coefficients W_{mn} and K_{np} for each mode are calculated.

A two layered backpropagation (MLP) network was used. A logsig function was used for each of the layers because it constrains the outputs to positive values only. The number of hidden layers was chosen arbitrarily at first and then modified to decrease training time/accuracy for the network. It was also decided to use a backpropagation network with momentum and adaptive learning. These functions allow the Sum Squared Error to escape from "local minima" which occur in some of the error surface graphs.

Without this "momentum", the network may become stuck in local minima and will not train to the actual minimum.

In known manner, the Neural Network is trained by reference to a body of experimental data. The various parameters input to the Network NN during training are seen in Fig. 14 and are: percentage of oil O, percentage of water W, percentage of gas G, temperature T, water conductivity σ , flow pattern FP and frequency F. Fluid pressure may additionally be calculated and input to the Network, since the volume of gas - and hence the microwave properties - are

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allow flow of material while still defining the extent of the cavity. A microwave transmitter 38 and a microwave receiver 40 are again provided, and as in the Fig. 1 embodiment the "walls" of the cavity, the emitter and the receiver are electrically insulated from the contents of the cavity.

It is possible to dispense with the grids 36, so that the liner 34 alone defines the resonant cavity, in which case certain modes of oscillation are lost but some remain and may be measured as before.

The embodiments of the invention illustrated in Figs. 1 and 16 utilise a receiver separate from the emitter, thereby measuring EM microwave energy input to the cavity as a function of frequency.

An alternative is to observe the reflected power at the transmitting antenna. This is observed by measuring the antenna's voltage standing wave ratio (VSWR). This has been done experimentally. A summary of the results taken separately in oil, gas and water are given in Fig. 17. At the lower frequencies the VSWR is sensitive to the presence of water, at medium frequencies it is sensitive to the presence of oil whilst only at high frequencies is the VSWR sensitive to the presence of gas. It is believed that the VSWR may be used as a rough indicator of the mixture composition.

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fluid material within the cavity.

6. An apparatus as claimed in any preceding claim wherein the resonant cavity has an inlet and an outlet such that the fluid material can flow through the cavity.

7. An apparatus as claimed in any preceding claim wherein the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

8. An apparatus as claimed in any of claims 1 to 6 wherein the means for detecting electromagnetic energy within the cavity comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio.

9. A device for monitoring constituents of a fluid flow comprising an apparatus as claimed in any preceding claim.

10. A device as claimed in claim 9, further comprising measurement electronics for determining the frequency of a resonance peak corresponding to a selected resonant mode within the cavity.

11. A device as claimed in claim 9 or claim 10, further comprising means for measuring additional properties of the fluid flow and calculating means for determining, on the basis of the measured properties, the proportions of certain constituents of the flow.

12. A device as claimed in claim 11, wherein the calculating means operates by calculating for a set of possible permutations of flow constituents the

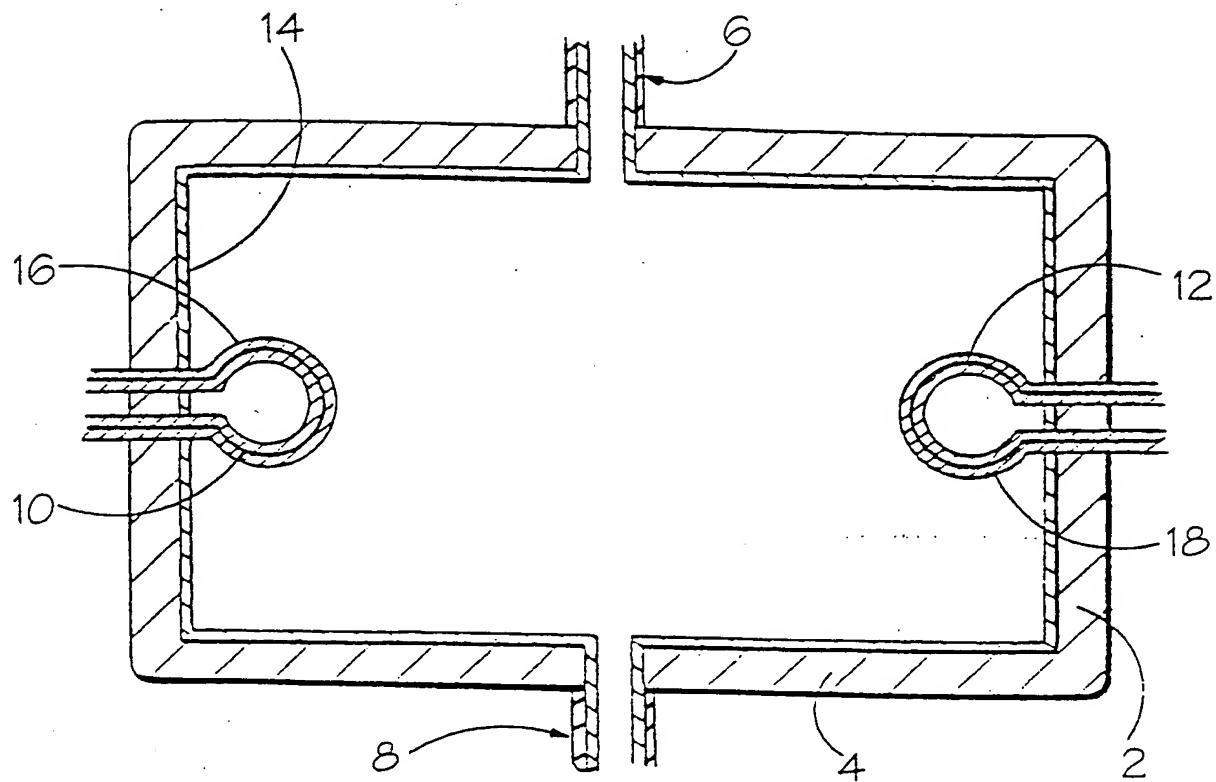
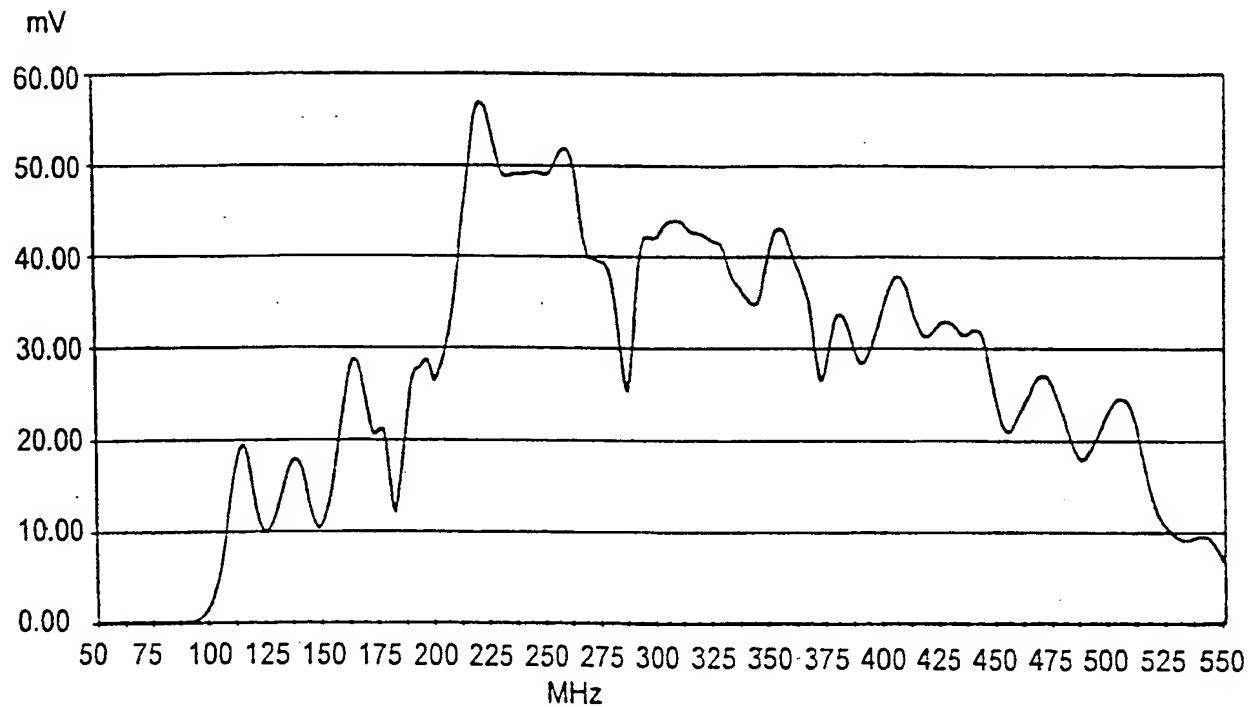
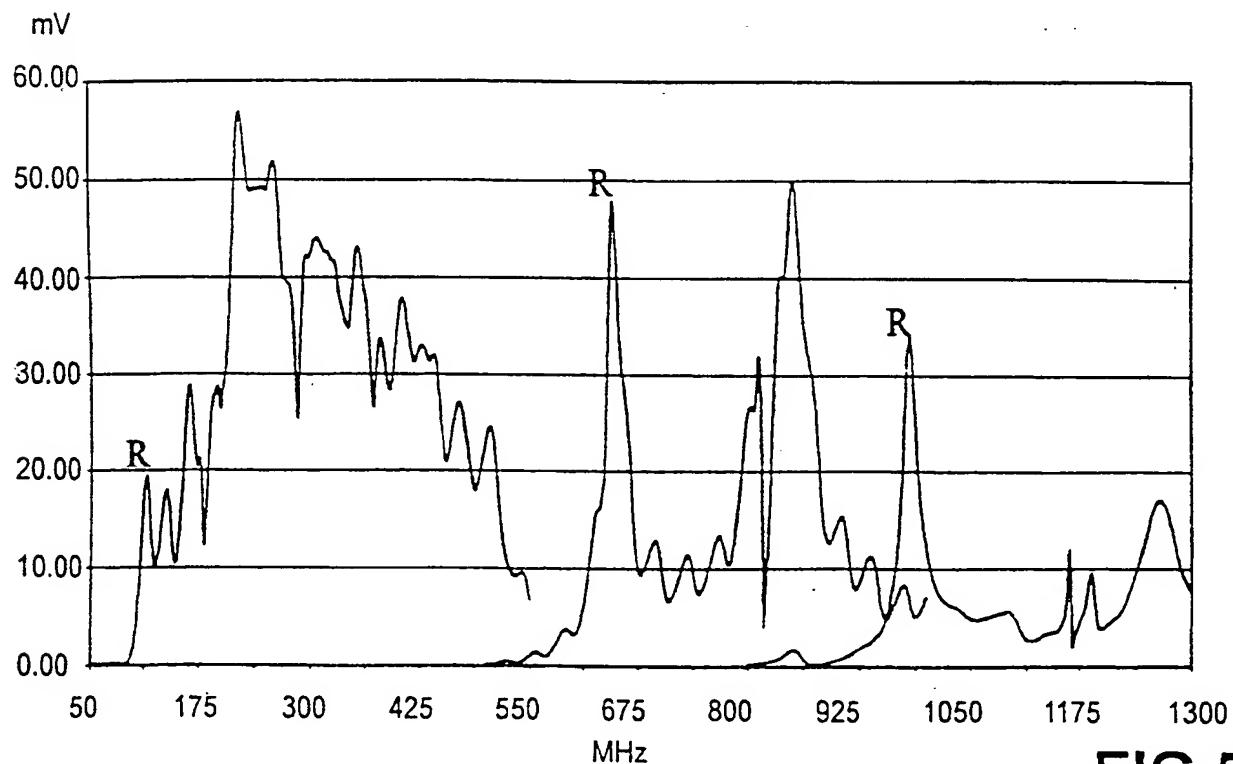


FIG.1.

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**FIG.4.****FIG.5.**

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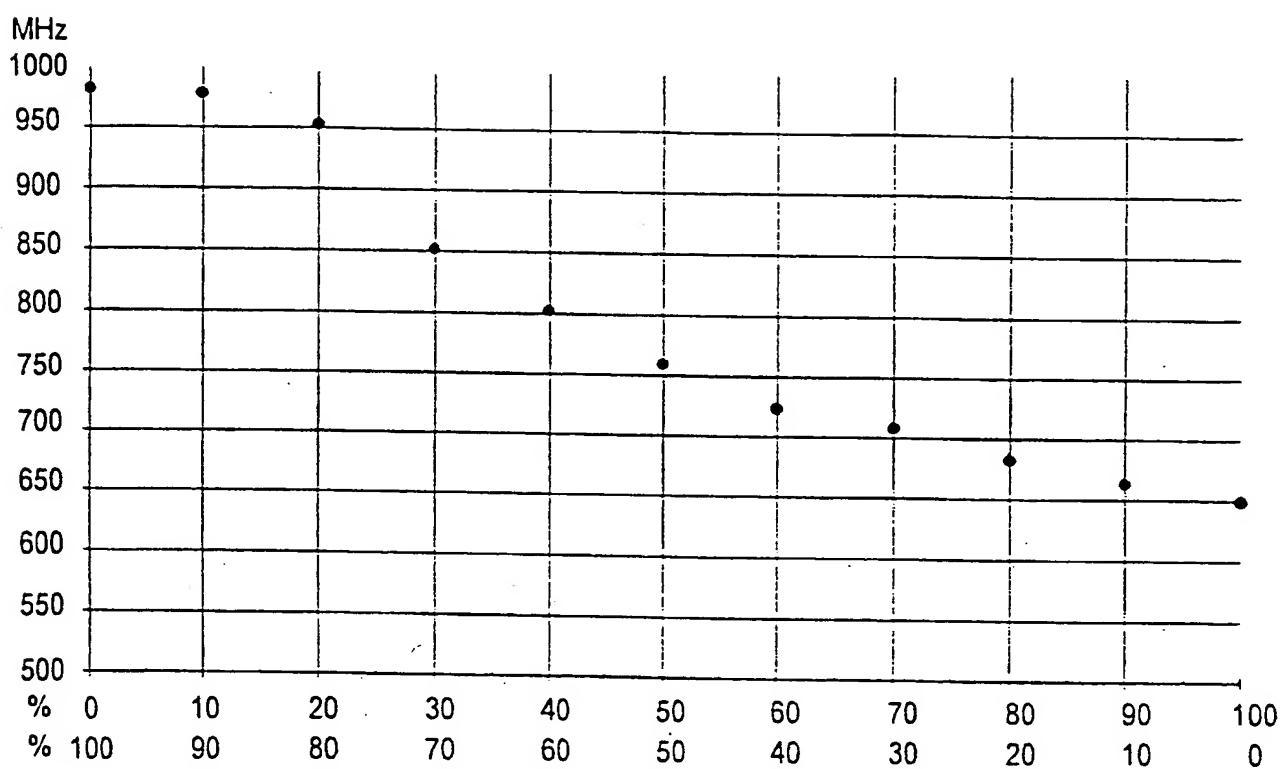


FIG.7.

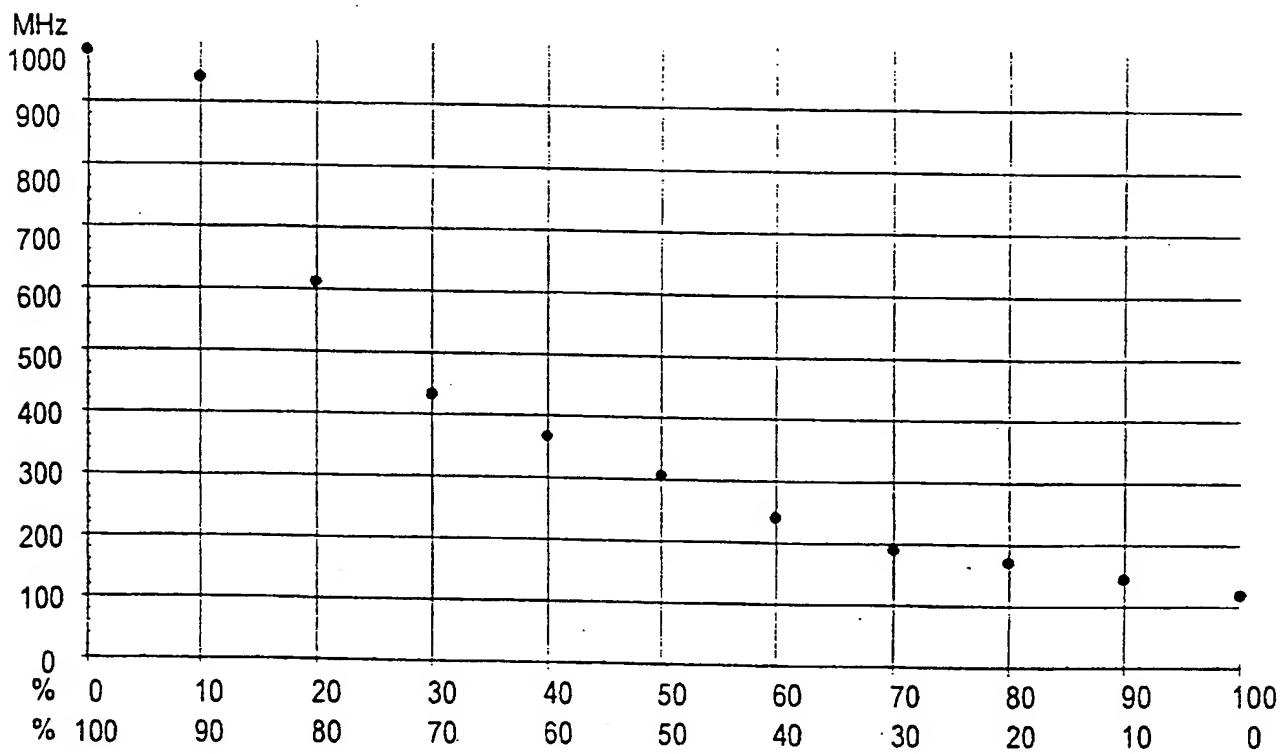


FIG.8.

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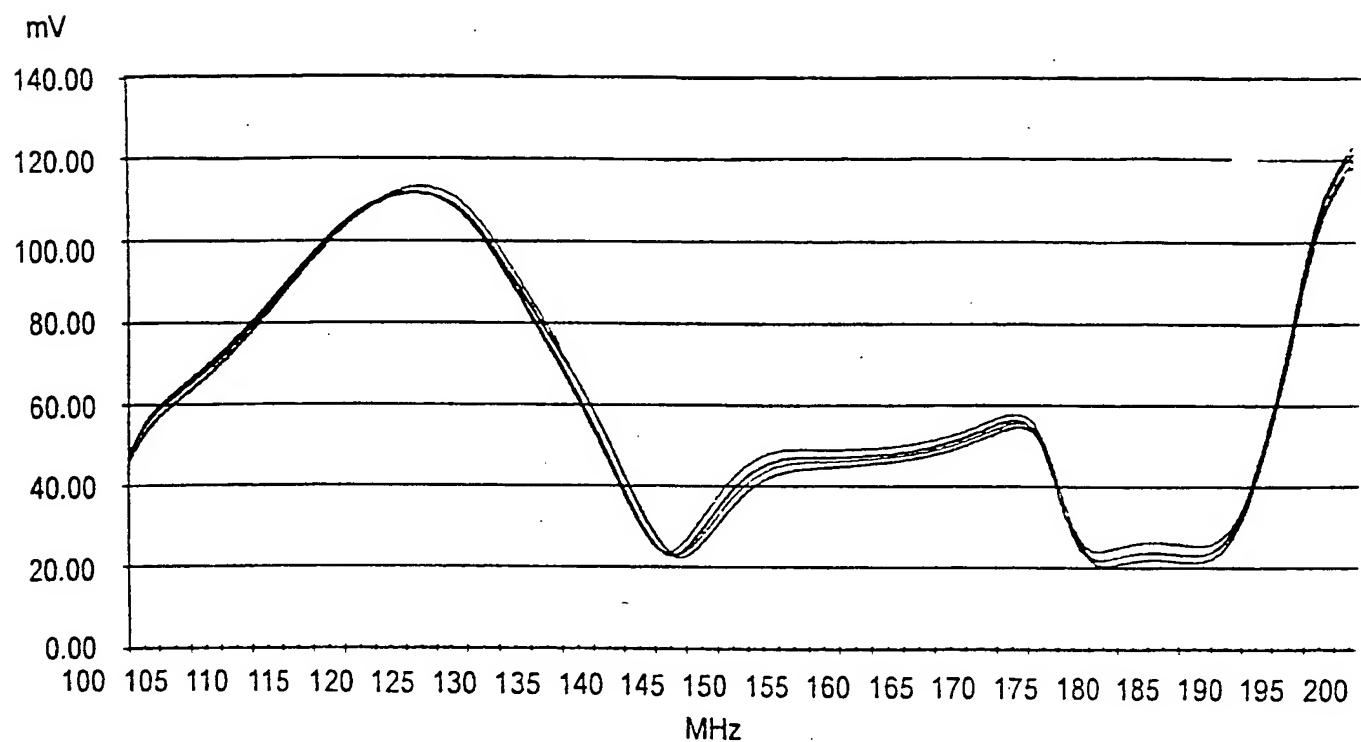


FIG.11.

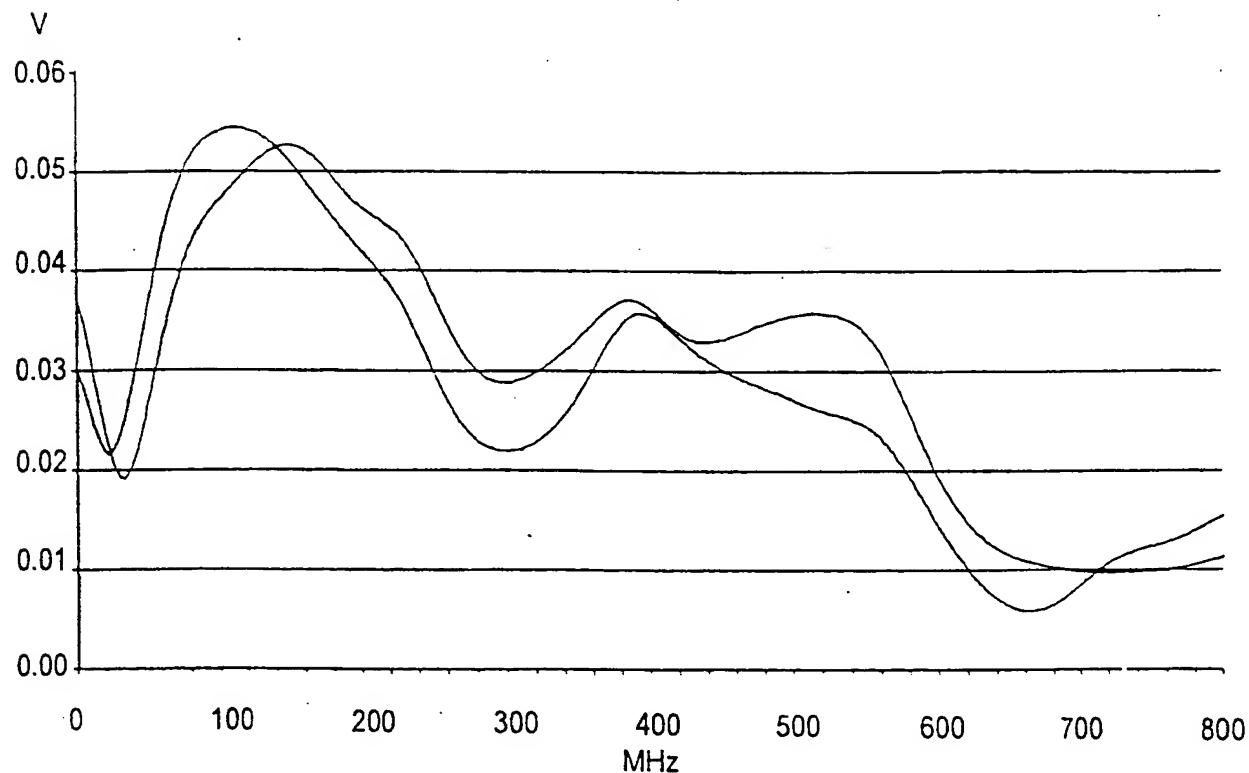
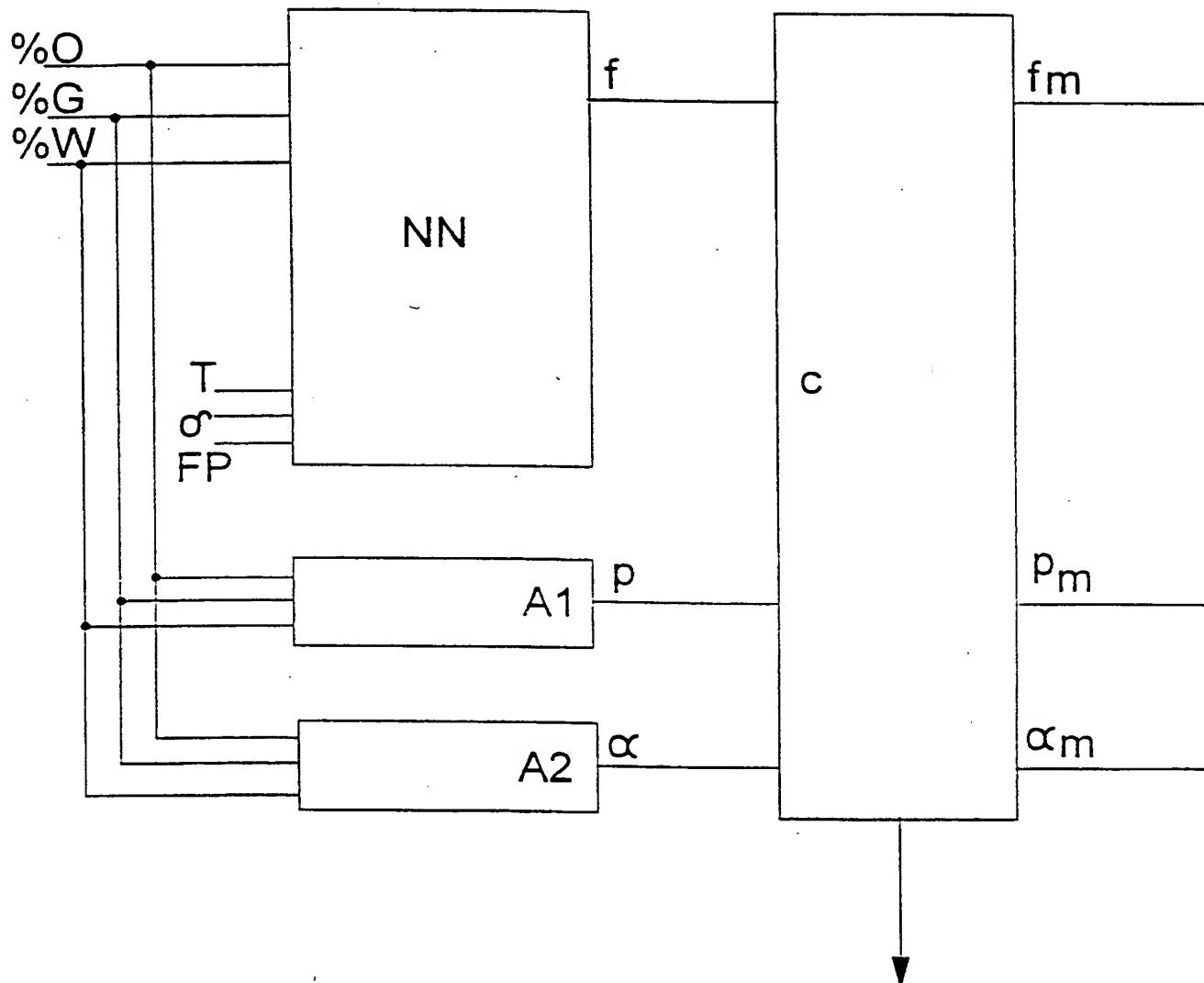


FIG.12.

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**FIG.15.**

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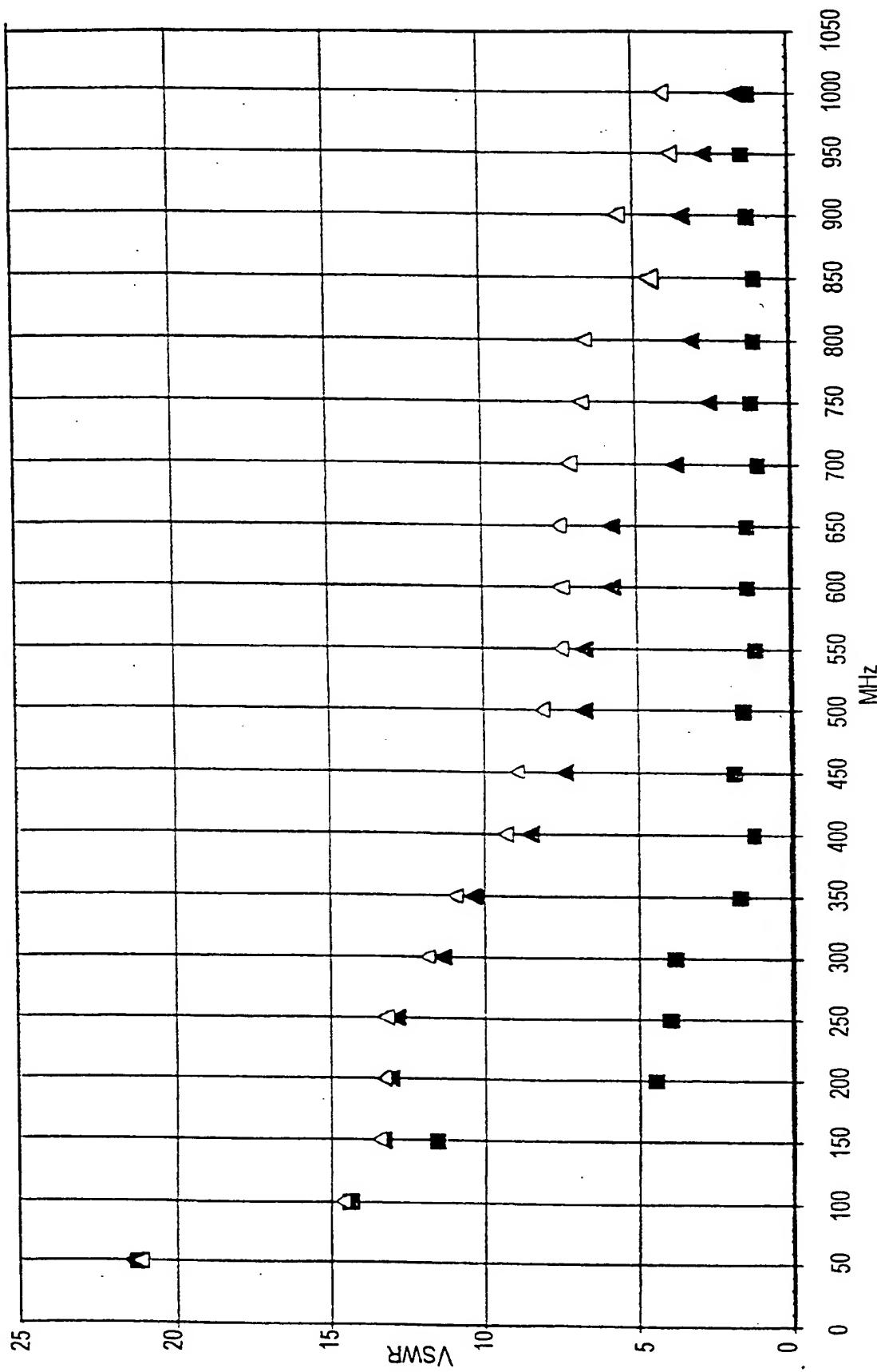


FIG.17.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/00168

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01N22/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

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20 March 2000

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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